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SHORT COMMUNICATION

Practical implications of motion correction with motion insensitive radial *k*-space acquisitions in MRI

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Objective: To highlight specific instances when radial *k*-space acquisitions in MRI result in image artifacts and how to ameliorate such artifacts.
Methods: We acquired axial T_2 weighted MR images on (1) the American College of Radiology (ACR) phantom and (2) a sedated sheep with rectilinear and multiblade radial *k*-space filling acquisitions. Images were acquired on four (2 × 1.5T and 2 × 3T) different MRI scanners. For the radial *k*-space acquisitions, we acquired images with and without motion correction. All images were visually inspected for the presence of artifact.
Results: Images collected via the conventional rectilinear method were of diagnostic quality and free of artifact. Both ACR and sheep images acquired with radial *k*-space acquisitions and motion correction suffered significant artifact at different slice locations, scan sessions and across all the four scanners. Severity of the artifact was associated with echo train length. However, the artifact was eliminated when motion correction was not employed.
Conclusion: When little to no motion is present, the use of motion correction with radial *k*-space acquisitions can compromise image quality. However, image quality is quickly improved, and the artifact eliminated, by repeating the scan without motion correction or by using a conventional rectilinear alternative.
Advances in Knowledge: By improving awareness and understanding of this artifact, MRI users will be able to adjust MRI protocols, resulting in more successful scanning sessions, better image quality, fewer call backs and increased diagnostic confidence.

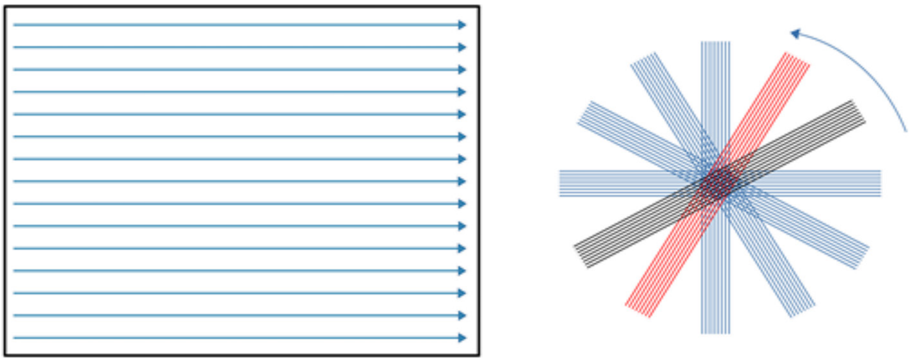
INTRODUCTION

In MRI, multiblade radial *k*-space acquisitions are an effective method to help reduce motion artifact.[1,2] Hence, this technique has become very popular in clinical practice. All major MRI vendors now offer their own version: General Electric (PROPELLER), Siemens (BLADE), Philips (Mulit-Vane), Hitachi (RADAR) and Toshiba (JET). As opposed to the conventional rectilinear method of filling *k*-space, radial *k*-space acquisitions do so in a rotational fashion, where multiple blades are collected in an overlapping radial style[3] (each blade is composed of several parallel phase-encoding lines, Figure 1).

This particular method of filling *k*-space allows the center of *k*-space (where the highest signal amplitudes are stored) to be oversampled. The oversampling of the center of *k*-space not only helps in increasing the overall signal to noise ratio of the resultant images, but more importantly, allows for the removal or correction of blades with motion. In brief, these motion insensitive techniques assess the inconsistencies in position (in-plane displacement), rotation and phase of each blade. Poor correlation between data in each blade indicates significant motion.[1,3] Accordingly, blades with motion can be either corrected or simply discarded; hence the final image should have substantial motion reduction.[4,5]

Motion insensitive radial *k*-space acquisitions are therefore a great boon for motion-prone patients (Figure 2). However, as we recently experienced, a greater understanding of the sequence can lead to improved image quality, explain puzzling artifacts and even reduce scan times. Radial *k*-space T_2 weighted imaging performed on the American College of Radiology (ACR) phantom produced a consistent

Figure 1. (Left) The standard rectilinear (line-by-line) method of filling *k*-space. (Right) the radial *k*-space sequence fills *k*-space in a rotational fashion. The black and red bands represent two of the blades used to fill *k*-space.



"motion-like" artifact on the resultant images (Figure 3). When using the same sequence on clinical human brain cases, we had not seen this artifact. We therefore set out to understand and reduce the presence of the identified artifact.

METHODS AND MATERIALS

ACR phantom imaging

Images of the ACR phantom were acquired on 4 different scanners (3T GE HDxt and 1.5T GE Signa Explorer with 8-channel head coils; and 3T Siemens Skyra and 1.5T Siemens Aera with 20-channel head coils).

On the 3T GE HDxt scanner, conventional rectilinear fast spin echo T_2 weighted images of the ACR phantom were acquired in the axial plane. In addition, two sets of two-dimensional (2D) T_2 weighted images were acquired with radial *k*-space acquisitions. The first set was acquired with the motion correction option on and the second without. The motion corrected data were also acquired with three different ETLs (40, 52 and 64) to demonstrate the effect of the ETL on the observed artifact. For both the rectilinear and the radial *k*-space scans, the imaging parameters were as follows: field of view (FOV) = 256 mm, number of slices = 11, slice thickness = 5 mm, interslice gap = 5 mm, repetition time (TR) = 4000 ms, echo time (TE) = 93 ms, flip angle = 142 degrees, matrix = 416 × 416 and one excitation; other imaging parameters were kept as similar as possible. Motion insensitive radial *k* space acquisitions with motion correction on and off, and conventional fast spin echo images were compared visually for the presence of artifact and image quality by the MR technologist acquiring the scans (MMA) and reporting radiologist (RJK).

In this short report, we display images acquired on the 3T GE HDxt scanner (Figure 3). However, the artifact was repeatable across multiple testing sessions collected several weeks apart and was present on all four scanners tested.

In vivo sheep imaging

As part of an ongoing research collaboration involving sheep, we acquired MR brain images of a sedated sheep on the 3T GE HDxt scanner. Imaging parameters were as follows: For the motion insensitive radial *k*-space (PROPELLER) scan: 2D, FOV = 212 mm, number of slices = 34, slice thickness = 2 mm, interslice gap = 2 mm, TR = 4500 ms, TE = 126 ms, flip angle = 142 degrees, matrix = 512 × 512, two excitations, an oversampling factor of 1.5 (ETL = 40) and motion correction "on". For the conventional fast spin echo run: 2D, FOV = 212 mm, number of slices = 34, slice thickness = 2 mm, interslice gap = 2 mm, TR = 3684 ms,

Figure 2. Axial brain images. (a) The effect of head motion on a conventional turbo spin echo T_2 weighted image. (b) Significantly reduced motion artifact after using the motion insensitive sequence.

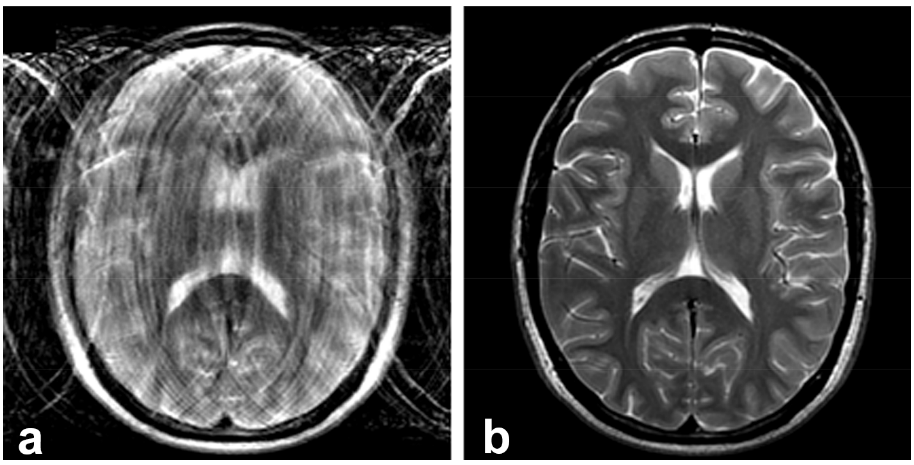
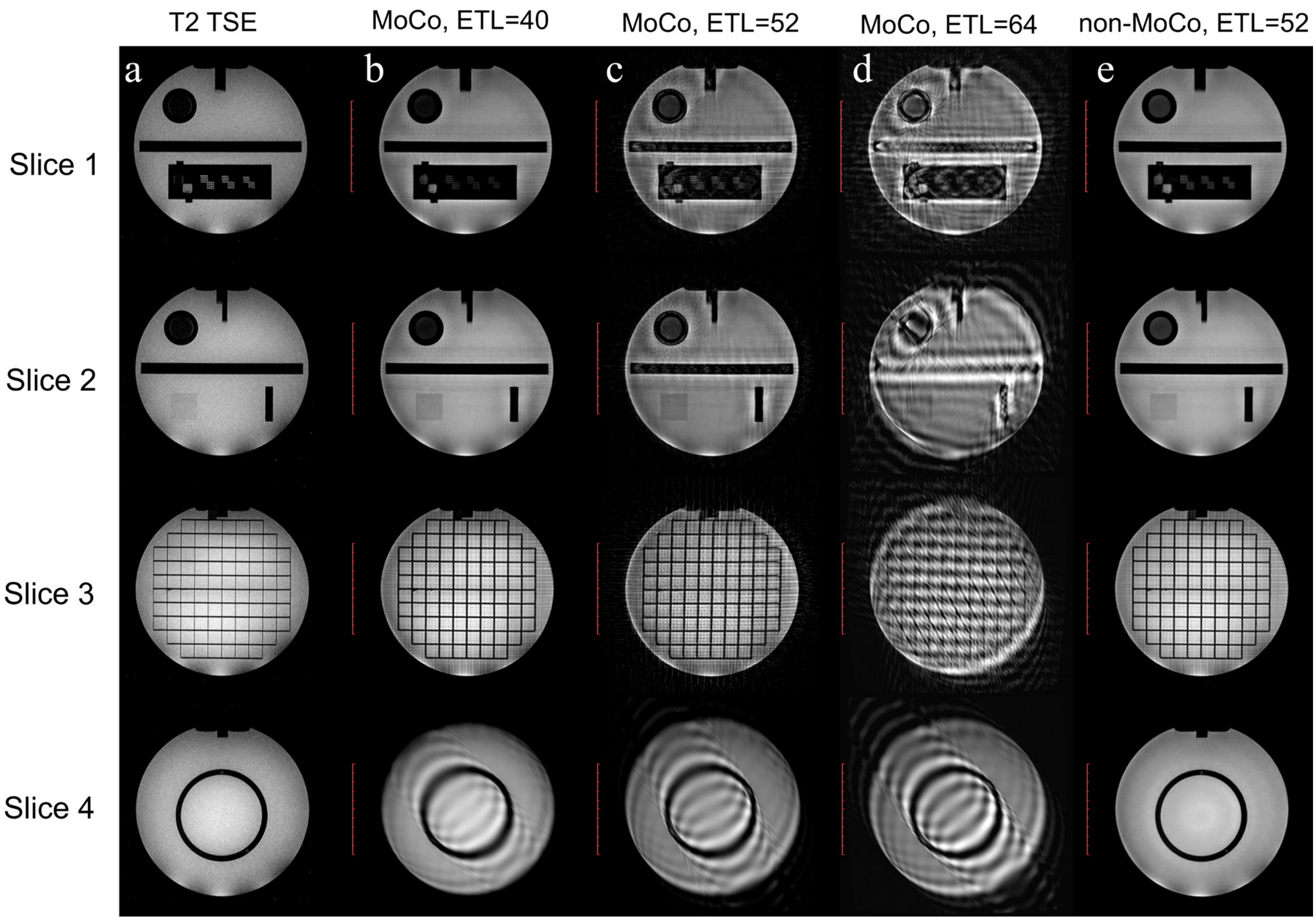


Figure 3. Axial T_2 weighted images of the ACR phantom. (a) Conventional rectilinear turbo spin echo images are clear and show no artifact. (b–d) Motion insensitive radial *k*-space motion corrected "MoCo" images with different ETLs. (e) non-motion corrected (radial *k*-space acquisition) images show no artifact. This figure demonstrates how motion correction and motion insensitive radial *k*-space acquisition data can cause artifact in situations with little to no motion. Upon switching the motion correction algorithm off, the artifact disappears (e). It is also important to note that the signal-to-noise, as well as the contrast of the images, deteriorates as the ETL increases (b–d). ACR, American College of Radiology; ETL, echo train length.



TE = 87 ms, flip angle = 90 degrees, matrix = 320 × 320 and two excitations. Note: the PROPELLER scan and the conventional fast spin echo imaging parameters did not match. These images were acquired in the context of short duration sedation; after the artifact was identified on the motion corrected radial *k*-space image and prior to reviving the sheep, we quickly acquired the conventional fast spin echo with slightly different parameters, which was artifact-free.

RESULTS

ACR phantom images

Conventional fast spin echo T_2 weighted images of the ACR phantom were of diagnostic quality and free of artifact. The radial *k*-space acquisitions with motion correction resulted in substantial "motion-like" artifact (Figure 3). Parallel imaging techniques (such as ASSET or GRAPPA) marginally reduced the severity of the artifact (data not shown). The degree of artifact increased with echo train length, indicating that the more blades (or oversampling), the worse the artifact. The radial *k*-space acquisitions without motion correction, however, resulted in artifact-free images (Figure 3e). This is an excellent example of the use of motion correction software applied to stationary objects (*i.e.* the ACR phantom), resulting in images corrupted by an artifact associated with the motion correction algorithm itself.

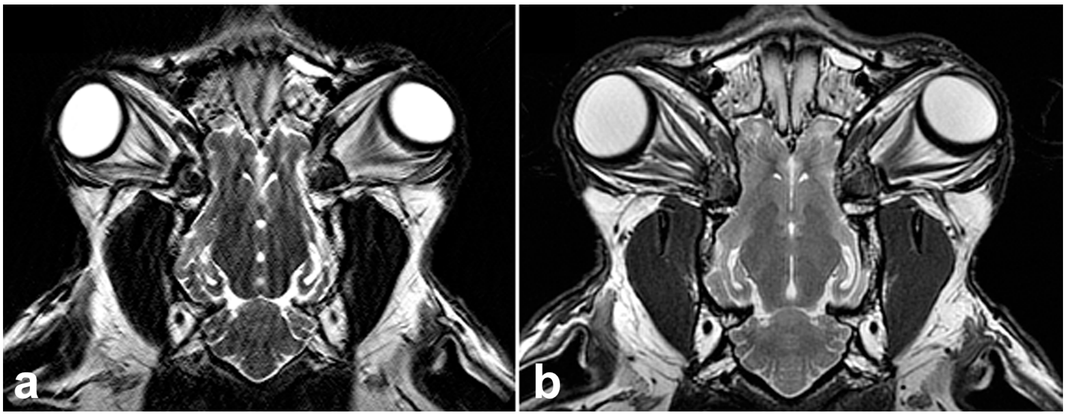
Sheep images

The sheep was first scanned with a radial *k*-space acquisition, with motion correction on. As the sheep was sedated, the sheep demonstrated very little head movement, hence the presence of the prominent artifact visible in Figure 4a. Upon identifying the artifact, we immediately acquired a second conventional turbo spin echo T_2 weighted image, resulting in an image free of this artifact (Figure 4b).

DISCUSSION

Motion insensitive radial *k*-space acquisitions are effective at improving image quality in a number of situations, specifically by reducing motion artifacts; they are rightfully well-accepted and an integral part of clinical MRI.[6–8] However, artifacts can appear when certain motion correction algorithms are applied in

Figure 4. Transverse brain images of a sedated sheep. (a) Axial motion corrected radial *k*-space T_2 weighted image demonstrating the artifact. (b) Axial conventional rectilinear fast spin echo T_2 weighted of the same sheep, in the same session, without the artifact.



cases where there is no or very minimal motion (Figures 3 and 4). Here, we provide two examples of how to easily eliminate this "over correction artifact": (1) de-select the motion correction option [referred to as "Harmonize" on GE (PROPELLER) and "Motion Correction" on Siemens (BLADE)] or (2) use a conventional rectilinear acquisition.

We believe that the images from the sedated sheep provide an excellent example of motion estimation error, or "over correction" when using motion correction with a radial *k*-space acquisition. We resolved the artifact by re-scanning the sheep with a conventional rectilinear acquisition. However, an equally-valid solution would have been to de-select the "motion correction" option at the time of scanning. This option was unknown to the MR technologists at the time of scanning and provided the motivation for this short report.

In the ACR phantom images, the artifact worsened as the ETL increased (*i.e.* as the density with which *k*-space was oversampled increased). As rotation and translation profiles of a blade are fed into each subsequent blade,[1,5] additional blades will serve to exacerbate the errors in *k*-space and strengthen the artifact in the resultant image. This artifact could be ameliorated by reducing the ETL or alternatively, de-selecting the "motion correction" option.

In situations where little to no motion is expected, for example when scanning a phantom or a general anesthesia case, radial *k*-space acquisitions can still be highly effective. However, in these cases, the use of motion correction may be counterproductive and generate additional artifacts that degrade image quality. This degraded image quality may in turn lead to reduced confidence or even misdiagnosis. If this type of artifact is present when using radial *k*-space acquisitions, we propose two simple solutions: (1) de-select the "motion correction" option at acquisition (this does not affect scan parameters or duration, as this is a post-processing step), or (2) switch to a conventional rectilinear turbo spin echo acquisition. We note that, by default, motion correction is "on" for GE PROPELLER sequences, but "off" for SIEMENS BLADE acquisitions.

In conclusion, we have highlighted a potential artifact associated with the use of motion corrected radial *k*-space acquisitions, known to some MR technologists and radiologists, but not all. When very little motion is present (such as when scanning a phantom or patients under general anesthesia/sedation), the use of such acquisitions can cause a reduction in image quality. Image quality is quickly improved, and the artifact eliminated, by repeating the scan without motion correction or by using a conventional rectilinear acquisition. By improving awareness and understanding of this artifact, MR technologists and radiologists will be able to adjust MRI protocols, resulting in more successful scanning sessions, better image quality, fewer call backs and increased diagnostic confidence.

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